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Planting density effects on growth and survival of four pine species after 22 and 30 years on the eastern Highland Rim, TN

Martin Roland Schubert

To the Graduate Council:

I am submitting herewith a thesis written by Martin Roland Schubert entitled "Planting density effects on growth and survival of four pine species after 22 and 30 years on the eastern Highland Rim, TN." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

John C. Rennie, Major Professor

We have read this thesis and recommend its acceptance:

Scott Schlarbaum, Arnold Saxton

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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PLANTING DENSITY EFFECTS ON GROWTH AND SURVIVAL OF FOUR PINE SPECIES AFTER 22 AND 30 YEARS ON THE EASTERN HIGHLAND RIM, TN

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Martin Roland Schubert
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ABSTRACT

Pinus taeda L. (loblolly pine), *P. Virginiana* Mill. (Virginia pine), *P. echinata* Mill. (shortleaf pine), and *P. strobus* L. (eastern white pine) were planted in two acre split plots at 6x6 foot spacings, 9x9 foot spacings, 12x12 foot spacings and 15x15 foot spacings on the eastern Highland Rim of Tennessee in 1965. The site was converted from hardwoods following a clearcut, injection of 2,4,5-T on cull trees and a prescribed burned. Height and diameter were measured at ages 22 and 30. Survival, tree dimensions (height, diameter, individual tree volume, and value per tree) and stand dimensions (basal area per acre, volume per acre and value per acre) were compared among spacings, species and for the combined affects of species and spacing on these parameters. By age 22, competition at the closest spacing had begun to decrease survival. Planting density had no consistent impact on height growth but diameter growth increased with each increase in initial spacing. Stand dimensions decreased as spacing increased. White pine and loblolly pine grew better on this site than shortleaf pine and Virginia pine. At 22 and 30 years, loblolly pine and white pine planted at a 6x6 foot spacing and followed closely by white pine at a 9x9 foot spacing had higher volumes than any species at all spacings. The greatest merchantable volume as expressed as a value per acre was achieved by white pine at the 9x9 foot spacing followed by white pine at all other spacings.

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CHAPTER I

INTRODUCTION

Softwood timber harvest from both industrial and nonindustrial private ownerships in the South have increased steadily since the 1960's with trends projected to continue into the next century (Adams and Haynes 1991). This demand for softwood timber is being met with an increasing dependence on pine plantations, as they are the most efficient and effective method of growing large volumes of fiber on the shortest rotation.

The increased area of plantations in the South is located on converted hardwood sites throughout the Piedmont, southern Coastal Plain and the upper Coastal Plain. The Appalachian Plateau of Tennessee, generally known as a hardwood region, has been largely overlooked for the production of softwood timber. Several successful plantations have been established, however, and with the ever growing demand for softwood fiber, the role of plantations in this area needs to be explored.

With the preconceptions of the area as a hardwood region, there is a lack of information on which foresters can base management decisions. What species grows best in this region and at what spacing? What kind of growth can be expected? What economic return is possible? Questions such as these need to be answered before any recommendations can be made.

Initial spacing can have a large influence on the productivity of a plantation. Over the years several spacing studies have explored these effects on various species throughout the East (Bennett 1960 and 1969, Clark and Saucier 1989 and 1991, Bramble, Cope and

Chisman 1949, Harms and Collins 1965, McClurkin 1976, Munger 1946, Russel 1958, Smith 1958, Ware and Stahelin 1948). Although the effect of initial spacing of trees on growth is fairly well understood, the specific effects on individual species is not. Spacing effects for Virginia pine (*Pinus virginiana*), shortleaf pine (*P. echinata*), loblolly pine (*P. taeda*), and eastern white pine (*P. strobus*) in Tennessee is not well documented. Therefore, understanding and documenting these effects impacts the decisions of forest managers throughout Tennessee and surrounding states. Some research on spacing has been done for loblolly pine. Documentation of the effects of spacing on growth of the other three species is scarce or nonexistent. Virtually all research in the area has been conducted outside of Tennessee and this spacing study is the only one known by the author to contain these four pine species in the same plantation.

The objectives of the research reported in this thesis were to:

1. Determine the effect of spacing on survival and production of four pine species
2. Determine the differences in survival and production among species
3. Determine the combined effect of spacing and species on survival and production of four pine species.

These objectives were evaluated both at 22 and 30 years from establishment.

CHAPTER II

LITERATURE REVIEW

Plantations Versus Natural Regeneration

Managers have several issues to address when they face the initial decision of whether to establish a plantation or allow an area to naturally regenerate. Establishment costs, site preparation, speed of regeneration, genetic variability, availability of genetically superior seedlings, self-pruning of limbs and diversity of habitat for wildlife should all be considered before this decision is made.

Plantations have many benefits. They concentrate growth on the desired species and the initial spacing of the species can be controlled to produce the desired product. It is possible to have genetically superior seedlings selected for growth and quality of form. Tree improvement programs have greatly improved the success of pine plantations by breeding for traits such as rate of growth, stem straightness, limbs, and resistance to disease. Artificial regeneration is also independent of local availability of a seed source. There is also less idle time needed in establishing new stands.

Some drawbacks to plantations are their cost of establishment and the lack of species variability, which may adversely affect wildlife. There are also fewer stems per acre using artificial regeneration than with natural regeneration so that trees tend to have more branches in all but the closest spacings.

With natural regeneration, establishment costs are minimized. There also tends to be greater number of plants which helps prune lower branches as well as variation in species composition which might benefit wildlife. This variation, however, takes valuable resources from the desired crop trees and initial savings from establishment may be offset by the need for more silvicultural treatments early in the rotation to remove individual stems, species or both. Regeneration is dependent on local seed sources which are not always available or of good quality, and the regeneration that does occur may be spotty at best. Initial overstocking also tends to be a problem and some pre-commercial thinning is usually required.

Tree Planting in the South

Between 1890 and 1933 the South had been heavily cut. Commercial forest area was estimated at 190.8 million acres of which 43.4 million acres were poorly stocked. In 1933, the South had over 100 million acres of cutover pine land. (Young and Mustian 1989) The Tennessee Valley alone contained 20 million acres of abused and cutover land as well as 13 million acres of cultivated land, 2 million of which was severely eroded (Barber 1989).

With the creation of both the Civilian Conservation Corps and the Tennessee Valley Authority (TVA) in 1933, emphasis moved toward reforestation and recovery of the regions resources. Between 1933 and 1942, the Corps planted 129 million trees on Federal, state and private land. Between 1942 and 1957, TVA continued its planting efforts, reclaiming 240,000 acres of mostly eroded land. (Barber 1989)

Industrial planting has been slower in initiation. From 1925 through 1945, industry planted 139,000 acres. Since 1945, industrial planting has risen steadily and dramatically through 1985. In 1985, forest industry, mining, railroad and utility companies combined to plant 1.2 million acres, accounting for sixty percent of all area planted in the South (Barber 1989).

Federal and state incentive programs have provided an increase of planting on private lands in the late 1970's through 1985. The Forestry Incentives Program has given a major boost to tree planting in the South with an average annual area of 158,530 acres planted under the program from 1980-84 with total planting on nonindustrial private land averaged 452,837 acres annually (Barber 1989).

Projections through 2040 indicate pine plantation area increasing by 22 million acres in the South while natural pine stands decline by an approximate 20 million acres (USDA Forest Service 1989).

Species Selection

The selection of species is an important factor in the long term success of a plantation. Matching the species to the site is foremost in maintaining a vigorous stand.

Loblolly Pine. Loblolly pine's natural range extends into some of Tennessee's southern counties, but it is not considered native to Franklin County. It has been successfully planted throughout Tennessee. Loftus (1974) reported good growth and survival for loblolly pine on the eastern Highland Rim. He found loblolly pine heights and diameters were larger than Virginia pine, shortleaf pine and white pine at ten years. McGee (1980) reported excellent survival of planted loblolly pine on the Cumberland Plateau.

Shortleaf Pine. Shortleaf pine is the most prevalent pine in Tennessee. In a planting in west Tennessee, shortleaf pine had better survival than loblolly pine (Williston 1959). Williston and Balmer (1980) reported slower growth of shortleaf pine in the sapling stage than loblolly pine with shortleaf pine doing well after 20 years.

Virginia Pine. Virginia pine is found naturally throughout the eastern half of Tennessee, often on abandoned agricultural lands. Belanger and Bramlett (1979) report that maximum volume growth of Virginia pine stands results from stands with high basal areas. Virginia pine at age ten has grown faster than both shortleaf pine and eastern white pine on a site near Tullahoma, TN and on three sites near Sewanee, TN (Loftus 1974).

Eastern White Pine. The range of eastern white pine extends down the Southern Appalachians and Cumberland Mountains and Plateau of eastern Tennessee into northern Georgia. White pine is found between elevations of 1000-4000 feet on a variety of soil types. Eastern white pine is one of the fastest growing species in the interior South. Loftus (1974), however, reported slow ten year growth for white pine on the eastern Highland Rim. Twenty year growth in the Ridge and Valley physiographic region indicated much better growth and survival (Burton 1964). White pine is a slower growing tree initially and is negatively affected by poorly drained soil. McGee (1980) reported excellent survival of planted white pine on the Cumberland Plateau.

Factors Determining Spacing Decisions

Factors determining decisions of spacing to be used in plantations are:

1. establishment cost, 2. mortality, 3. intermediate removals, 4. rotation length, and 5. available markets of products.

Establishment Costs. The cost of establishing a plantation can exceed the return without proper planning and careful consideration of all the associated costs. Realization that every management action carries a cost should influence every decision made. The greatest costs are incurred with the artificial regeneration of a stand. Initial preparation of the planting site must be considered as well as the fact that each seedling planted comes at a cost both in itself and also in the time and effort on planting.

Site Preparation. Site preparation increases survival and aids in height growth when converting hardwoods sites to pine on the Highland Rim (Thor and Huffman 1969). In a study of six site preparation treatments Edwards (1994) demonstrated that loblolly pine planted after more intensive site preparation methods had better survival and growth up to age ten. Light is the most important resource limiting growth of planted white pine seedlings in the Southern Appalachians (Elliot and Vose 1995). The goal of site preparation, therefore, is to prevent competition until the crowns of the planted species close and are able to exclude the natural regeneration. Naturally, the wider the initial spacing, the longer time until canopy closure and exclusion of competing species. Lower establishment densities will require more intensive site preparation in the attempt to slow competition growth until the species exclusion stage. Elliot and Vose (1993) showed that planted white pine growth improved on clearcut and burned sites in Southern Appalachian pine-hardwood stands. Burning tends to be the most efficient method of site preparation due to its relative low cost to achieve. Freeman and Van Lear (1977) reported increased growth in white pine with the use of herbicides.

Planting Density. Planting costs vary with different planting densities. Naturally, at closer spacings there are more trees per acre and the price of each additional seedling must be added to the cost of planting at closer spacings. Decreasing spacing from x to x-3 foot spacing (i.e., 12x12 to 9x9 foot spacing) almost doubles the number of seedlings to be planted. More difficult to measure but equally important is the cost associated with the additional labor of planting more seedlings. Ware and Stahelin (1948) reported that a 6x6 foot spacing was the most economical with a savings in planting and time of timber production offset by loss in quality at wider spacings. Russell (1958) stated that a 6x6 foot spacing and a 6x8 foot spacing balance planting costs with satisfactory early growth rates. Conrad, Straka and Watson (1990) reported that wider spacings (9x10 foot spacing) produced higher returns for both pulpwood and sawtimber.

Expected Mortality. Mortality of some of the planted seedlings should be expected. Excess mortality due to an overstocked stand should be avoided. At closer spacings, planted trees begin competing for resources earlier than at wider spacings (Russell 1979, Ware and Stahelin 1948, McClurkin 1976). This competition begins to suppress the growth of trees leading to their eventual mortality. At wider spacings, there are fewer trees competing for the same resources increasing the availability of those resources to each individual tree thus reducing mortality.

Intermediate Removals. An intermediate harvest, or thinning, in a dense stand can reduce the competition among those trees. It is widely accepted that thinning reduces the overall cubic foot volumes as well as board foot volumes of a stand. Thinning, however, increases the diameter and height growth in fewer trees thereby concentrating growth on the crop trees. Most studies regarding the effect of thinning on the growth and yield of a stand compare two stands at the same initial density and fail to compare a thinned stand to a unthinned stand whose initial stocking is the same as the residual thinned stand.

Rotation Length. Rotation length has a profound effect on the consideration of initial spacing. Closer initial spacings will have more trees per acre adding volume. Although the growth is smaller per tree than those trees planted at wider spacings, the difference in the number of stems per acre maintains a higher volume growth then at the wider spacings. For longer rotations, stands will undergo increased competition, slowing growth and eventually self thin through the mortality of suppressed trees. Wider spacings can reduce the amount of mortality which occurs at longer rotations. Loss of volume due to higher mortality at closer spacings will reduce the overall volume below the volumes of stands planted at wider spacings and reduced mortality.

Availability of Markets. The markets to which timber is sold affects the decision of spacing. If a regional market exists for pulpwood but not for sawtimber, rotation length may be shortened allowing for a closer spacing. If no pulpwood market exists, the possibility for using a closer spacing is eliminated.

Tree Growth Characteristics Affected by Spacing

Height Growth. Height growth is little affected by spacing (Bennett 1960, Ware and Stahelin 1948, McClurkin 1976). McClurkin (1976) did report a significant effect on height between the extreme 4x4 foot spacing and a 6x6 foot or 8x8 foot spacing leading to the conclusion that planting density has little effect on height growth as spacing approaches 8x8 feet.

Diameter Growth. It is generally accepted that wider spacings increase diameter growth. Ware and Stahelin (1948) reported average diameters about twice as great in 12x12 foot and 16x16 foot spacings as on unthinned 4x4 foot spacings with diameter growth at 14 years at 3-4 times as great for slash pine (*P. elliottii*), longleaf pine (*P. palustris*) and loblolly pine. Although annual diameter growth tends to decrease over time, that decline is significantly reduced with a decline in the number of stems per acre at establishment (Harms and Collins 1965).

Pruning. The number and size of limbs on the stem affects the quality and resulting value of a tree. Brazier (1977) states that trees have the same number of branches regardless of initial spacing, and although knot size increased with larger spacings the maximum variation in average branch diameter between spacings is minimal.

Form Class. In general, taper of the stem is greatest in open-grown trees and decreases with an increase in stocking density (Maris 1949). Since form class is the ratio of the diameter inside bark at the top of the first log to diameter at breast height (DBH), wider spacings reduce form class.

Specific Gravity. Specific gravity variability within species is a result of differences in the percentages of early- and latewood production. This percentage is moderately dictated by genetics but is more highly correlated with geographic location. More specifically, this geographic influence appears to be related to the climatic factors of temperature (length of growing season) and seasonal rainfall patterns (Clark and Saucier, 1991). Spacing has some influence on the specific gravity of wood during stand development. Trees at wider spacings had higher wood specific gravity then those at close spacings until crown closure when the reverse was true (Clark and Saucier 1991).

Size of Juvenile Wood Core. The size of the juvenile core is related to the rate of growth and the period to crown closure as influenced by initial spacing. Juvenile wood is grown at the crown of the tree and mature wood is grown on the clear bole of the tree (Clark and Saucier, 1991). Therefore, when trees begin to self prune after crown closure, the transition from juvenile to mature wood begins to move up the stem as well. Since crown closure occurs sooner at closer initial spacings and DBH is smaller, the juvenile core is smaller at closer initial spacings.

CHAPTER III

STUDY AREA

The 32 acre species-spacing study is located on the Highland Rim Forestry Experiment Station in Franklin County, TN., about four miles southeast of Tullahoma. The Highland Rim is characterized by topography which is generally flat with little relief.

The site is characterized by Dickson silt loam soils with a fragipan at a depth of 20-30 inches which limits permeability to air, water, and roots. Soils are acidic with low organic matter content and plant nutrients.

Elevation of the site is approximately 1000 feet above sea level. The climate is typically warm humid summers (July mean temperature and precipitation of 71°F and 12.45 inches, respectively). Average monthly winter temperatures range from 41-43°F and January precipitation averages 6.19 inches. Total annual precipitation is 57.6 inches per year. Franklin County averages 196 frost-free days.

The area where this study is located, Eastern Highland Rim, is often referred to as the "oak barrens" denoting the common current cover type and quality of growth. Southern red, post, and blackjack oaks are the most common species of the area. Site index for oak is approximately 50 feet, base age 50 years (Thor and Huffman 1969). This may be more a function of the frequent fires and post-settlement abuse of the area than severe soil and site limitations (Loftus 1974). Although the pine do not occur naturally, planted loblolly have generally been successful here (Loftus 1974, Thor and Huffman 1969).

CHAPTER IV

METHODS

Site Preparation

The site was previously occupied by naturally occurring hardwoods which were commercially clearcut in 1965. All cull trees were injected with 2,4-D and the area was mist-blown with 2,4,5-T to kill herbaceous material. Prescribed burning completed site preparation.

Seedlings

Loblolly and Virginia pine seedlings were provided by Hiwassee Land Company, Calhoun, Tennessee , from the Rose Island Nursery. The Tennessee Valley Authority's (TVA) Division of Forestry, Fisheries and Wildlife Development, Norris, Tennessee, supplied the eastern white pine and the shortleaf pine seedlings from the Clinton Nursery. Loblolly, Virginia and shortleaf pine seedlings were 1-0, while eastern white pine seedlings were 2-0.

Experimental Design

The design of the plantation was a randomized block, split-plot planting with four replications, as illustrated in Figure 1. Species were assigned to the whole plot and spacings within species were assigned to the subplots. Each plot is two acres (295 ft. x 295 ft.) and divided into four half-acre subplots (147.5 ft. x 147.5 ft.). The subplot treatments consist of spacings of 6x6, 9x9, 12x12, and 15x15 feet. Seedlings were

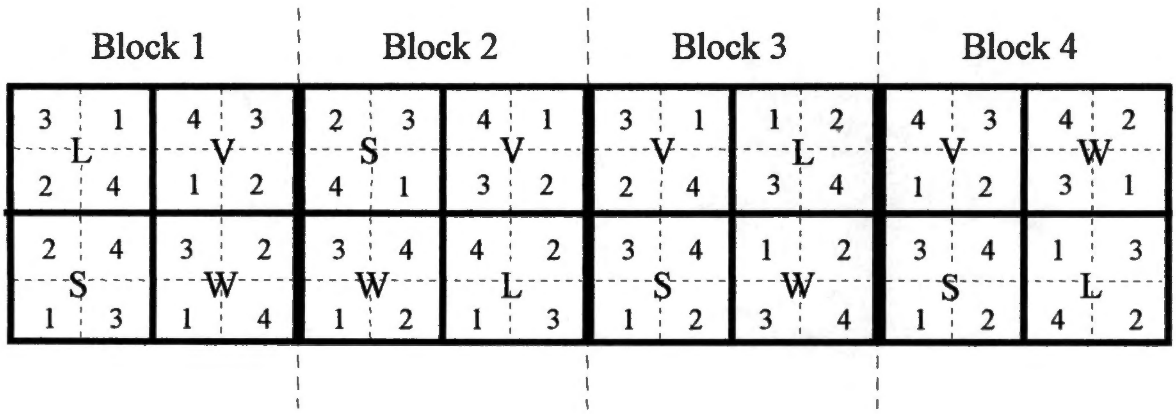

Figure 1. Plot map showing layout of study area. Letters represent whole plot treatments of the following species: L = loblolly pine, S = shortleaf pine, V = Virginia pine, and W = white pine. Numbers are subplot treatments of initial spacing and represent the following: 1 = 6x6 feet, 2 = 9x9 feet, 3 = 12x12 feet, and 4 = 15x15 feet.

planted in early spring of 1966. At the end of the first growing season, all dead seedlings were replaced. To minimize edge effect on measurements, only the inner ¼-acre (104.35 ft. x 104.35 ft.) trees of the ½-acre subplot are measured.

Sampling Methodology

The original experimental design included a sampling scheme for selecting sample trees within spacing. Measurements of the 6x6 foot spacing were begun with the fifth row from the southwest corner of the treatment plot, measuring every sixth row thereafter for three measured rows. Measurements begin with the fourth tree from the south side of the plot for a total of 51 trees inventoried: a 4.2% sampling intensity.

Measurements of the 9x9 foot spacing were begun with the third row from the southwest corner of the treatment plot measuring every third row thereafter for four measured rows. Measurements are begun with the third tree from the south side of the plot for a total of 48 trees inventoried: an 8.9% sampling intensity.

Measurements of the 12x12 foot spacings began with the second row from the southwest corner of the treatment plot measuring every other row thereafter for a total of five rows measured. Measurements of the rows begin with the second tree from the south edge of the plot for a total of 50 trees measured: a 16.5% sampling intensity.

Measurements of the 15x15 foot spacing begin with the second row from the southwest corner of the treatment plot and the second tree of each row for a total of eight trees per row with seven rows inventoried. A total of 56 trees are inventoried for a 28.9% sampling intensity.

Previous Measurements

Height of seedlings at establishment was recorded in the spring of 1966. Height and survival after the first growing season was recorded in November 1966. Mortality after the first growing season was replanted. In November 1967, height and survival, including replant trees, was recorded. At the end of five growing seasons, January 1971, a survival count was taken of all trees and trees were measured for height.

After ten growing seasons DBH, total height, and height to the first live branch were measured (Omiyale 1976). The sampling intensities for the 6x6, 9x9, 12x12 and 15x15 foot spacings were 4.2%, 8.9%, 16.5% and 28.9%, respectively. This was achieved by measuring predetermined rows within the subplots.

Sixteen-year measurements were of DBH, total height, height to the live crown, height to the first remaining branch, and crown radius. For white pine, two additional measurements were made. These were the number of branches in a whorl nearest breast height and the diameter of the largest branch in that whorl (Miller 1982). These measurements were taken on all the trees planted on the 15x15 foot spacing sub-plots, 50% of the trees planted on the 12x12 foot spacing sub-plots, 33% of the 9x9 foot spacing sub-plots and 16.6% of the 6x6 foot spacing sub-plots. Surviving overstory hardwoods caused some changes in the sampling methodology. Trees within 23 feet of an overstory hardwood were not included in the sampling process. Therefore, sampling did not necessarily include trees according to row as described above in the sampling methodology.

Height and diameter at age 22 were recorded in 1988 following the sampling methodology stated above. All surviving planted pine trees were measured without regard for hardwood survival or in-growth. Portions of several subplots that had the wrong species planted in them were recorded and noted.

Present Measurements

In the early spring of 1996, height and diameter were again measured using a Suunto clinometer, 100 foot tape and diameter tape. Effort was made to remain consistent with the original layout measurements even when discrepancies appeared with past measurements. In such cases, data for both the rows which were in the original plot layout and the rows which were measured in past years were collected. Actual sampling intensities averaged for all plots and blocks per spacing were 8.5% at the 4x4 foot spacing, 17.6% at the 9x9 foot spacing, 32.1% at the 12x12 foot spacing and 28.9% at the 15x15 foot spacing.

Several problems in the study were recognized while collecting the data in 1996. Portions of several subplots had the wrong species planted in them. It was decided to eliminate these individual trees from the sampling thereby reducing the number of trees for the subplot, a decision which had to be accounted for when calculating survival and doing the expansion calculations for all data. On several subplots, it was noted that the previous measurements of rows did not coincide with the current rows being measured, i.e., trees being present where previous mortality had been recorded. As a result, the row was measured according to the sampling methodology stated above as well as the row which matched the previous years measurements. This increased the sampling intensity of those plots thus affected. Three trees on two subplots had no heights recorded in 1996. This resulted in eliminating those individual trees from contributing to the average height per acre calculated for this subplot as well as calculations for deriving volumes for these trees and the volume per acre for those subplots.

Calculations

Programs were written to calculate individual tree basal area (BA) and volume (ft^3) from the 1988 and 1996 (22 and 30 year) DBH and height measurements for the in SAS. Stand basal area (ft^2/ac) was calculated by multiplying the plot total by four (plots per acre) and dividing by the sampling intensity as a proportion.

Individual tree volume was calculated with the form-class segmented-profile model from Clark, Souter and Schlagel (1991). The tree measurements used were total height and DBH. The form-class segmented-profile model equation for calculating volume between any two heights was used to calculate the volume of each standing tree. Diameter at 17.3 feet, necessary for calculating the total volume, was determined using a separate formula included in Clark et al. (1991). Coefficients for estimating diameter outside bark (DOB), also included in Clark et al. (1991) were used from the upper Coastal Plain coefficients for loblolly pine, shortleaf pine, and Virginia pine and from the Appalachian Mountains for eastern white pine. The Appalachian Mountain coefficients were used for white pine because no such coefficients were made available for the upper Coastal Plain. For a complete representation of the formula used, see Figure A-1. The mean of the volumes of the trees measured on each plot was calculated. Stand volume (ft^3/ac) was derived for each plot by multiplying the mean tree volume by the number of stems per acre.

In determining the monetary value of each tree, the volumes of sawtimber and pulp roundwood were calculated. This involved adjusting the form-class segmented-profile model equation used for total volume. First, trees were separated into those which were pulpwood size (less than 10 inches DBH) and those which were large enough for sawtimber (greater than or equal to 10 inches DBH). For both size classes, a stump height was set to 0.5 feet.

Pulpwood timber volume was estimated from 0.5 feet to a four inch diameter inside bark (DIB) top. In doing so, height to a four inch top was estimated under the assumption that height is a decreasing function of diameter squared (Clark et al. 1991); see Figure A-2. Once height to the four inch top was calculated, the form-class segmented-profile model equation for estimating volume of the stem between any two heights was used to solve for pole timber volume.

Sawtimber trees had sawtimber stemwood volume between the 0.5 foot stump to a six inch DIB top (Tennessee Forest Products Bulletin) and pulp topwood volume from the six inch top to a four inch top. Height to the six inch top was estimated again under the assumption that height is a decreasing function of diameter squared; see Figure A-2. After height to a six inch diameter was determined, it was rounded down to the nearest eight foot half-log (Tennessee Forest Products Bulletin). The sawtimber volume was then calculated using the form-class segmented-profile model equation solving for stem volume between the 0.5 foot stump and the height nearest a six inch top rounded down to the eight foot half-log. Topwood pulp volume was determined by using the calculated height of the last eight foot half-log as the lower height and the calculated height to the four inch top as the upper height. These variable heights were then used in the form-class segmented-profile model equation to solve for the topwood pulp volume.

The form-class segmented-profile equations determine the volume of a tree in cubic feet. Delivered prices in 1988 for pine pulpwood was $66.88 per cord and yellow pine sawtimber was $200.00 per thousand board feet (MBF) delivered and $280.00 per MBF delivered for white pine (Tennessee Forest Products Bulletin). Volumes were therefore converted to cords for pulpwood and MBF for sawtimber. Volumes were converted using 160 ft^3/MBF and 90 ft^3/cord (Toennisson and Hadden 1992).

Final data consisted of height, DBH, BA, pulpwood and sawtimber volume, and dollar value for each tree inventoried at 22 years and at 30 years since establishment.

Statistical Analysis

Mean tree height (ft), mean tree DBH (in), basal area (ft^2/ac) and volume (ft^3/ac) were calculated for each subplot. Analysis for significance was done using mixed model ANOVA to determine interactions of the main effects and comparing differences between the means of subplots across blocks using pairwise contrasts. A mixed model analysis program written by Dr. Arnold Saxton, of the Tennessee Agricultural Experiment Station Statistical Services, for use in SAS, was adapted for use in this study. The statistical model with class variables of block = i, species = j and spacing = k is:

$$Y_{ijk} = u + f_i + v_j + fv_{ij} + c_k + cv_{jk} + e_{ijk}$$

Tukey-Kramer's test was performed for all variables (spacing, species and spacing within species) with a probability level of $P<0.05$.

CHAPTER V

RESULTS

Survival

Survival is important when considering the cost of planting by initial spacing and recovering that cost at final harvest. At planting, there are 1210 stems per acre (spa) at the 6x6 foot spacing, 538 spa at the 9x9 foot spacing, 303 spa at the 12x12 foot spacing and 194 spa at the 15x15 foot spacing.

The test for fixed effects of species and spacing at 22 and 30 years from establishment revealed that species did not have a significant effect on survival while spacing and species*spacing were significant (Table 1). White pine had the highest overall survival at 22 years (74.00%) and at 30 years (64.63%), but was not significantly greater than any other species. Spacing showed significant differences because survival was significantly lower at the 6x6 foot spacing at 22 and 30 years (Table 2). At 22 years, the 9x9 foot spacing had the highest survival at 68.86%, but was not significantly greater than the 12x12 foot spacing (68.18%) and the 15x15 foot spacing (67.38%). At 30 years, the 12x12 foot spacing had the highest survival at 64.03%, but was not significantly greater than the 15x15 foot spacing (63.79%) or the 9x9 foot spacing (58.40%).

Twenty-two year survival was lowest at the 6x6 foot spacing for all species except shortleaf pine, where it was lowest at the 12x12 foot spacings (Table 3). White pine survival ranged from 87.05% at the 15x15 foot spacing to 52.94% at the 6x6 foot spacing. White pine survival was significantly smaller at the 6x6 foot spacing than at all other

Table 1. F-values and associated probability for fixed effects of species and spacing and the combined effects of species and spacing on survival at 22 and 30 years from establishment for the species-spacing comparison study at Tullahoma, TN.

	22 Years		30 Years	
Source	Type III F	Pr > F	Type III F	Pr >F
Species	2.37	0.1381	2.65	0.1120
Spacing	11.77	0.0001	48.55	0.0001
Species * Spacing	7.80	0.0001	5.99	0.0001

Table 2. Least square estimates of survival by spacing and species at 22 and 30 years from establishment for the species-spacing comparison study at Tullahoma, TN.

Source		Survival (%)	
Spacing (feet)	Species	LSMean 22 Years	30 Years
6x6		57.03 B*	39.30 B
9x9		68.86 A	58.40 A
12x12		68.18 A	64.03 A
15x15		67.38 A	63.79 A
	Loblolly Pine	64.59 A	59.33 A
	Shortleaf Pine	56.15 A	49.51 A
	Virginia Pine	66.70 A	52.07 A
	E. White Pine	74.00 A	64.63 A

* Different letters designate significant differences at 0.05 level among spacing and among species within year of measurement.

Table 3. Least square estimate of survival by spacing for each species at 22 and 30 years from establishment for the species-spacing comparison study at Tullahoma, TN.

Source		Survival (%)	
Spacing (feet)	Species	LSMean 22 Years	30 Years
6x6	Loblolly Pine	54.90 bf*	43.14 efg
9x9	Loblolly Pine	62.50 abcde	56.77 abcde
12x12	Loblolly Pine	76.00 abcde	73.00 ab
15x15	Loblolly Pine	64.95 abcde	64.40 abcd
6x6	Shortleaf Pine	54.90 bcde	44.61 cdef
9x9	Shortleaf Pine	67.19 abcd	56.25 abcde
12x12	Shortleaf Pine	49.35 ef	46.29 cdef
15x15	Shortleaf Pine	53.15 cdef	50.89 bcdef
6x6	Virginia Pine	65.36 abcde	29.26 f
9x9	Virginia Pine	70.23 abcde	57.58 abcde
12x12	Virginia Pine	66.87 abcde	62.34 abcde
15x15	Virginia Pine	64.36 abcde	59.09 abcde
6x6	E. White Pine	52.94 def	40.20 fg
9x9	E. White Pine	75.52 abce	63.02 bcde
12x12	E. White Pine	80.50 ab	74.50 ab
15x15	E. White Pine	87.05 a	80.80 a

* Different letters designate significant differences at 0.05 level among spacing and species by year of measurement.

spacings. Loblolly pine survival at 22 years was highest at the 12x12 foot spacing (76.00%) but was not significantly higher than at any other spacing. Shortleaf pine survival was significantly lower at the 12x12 foot spacing (49.35%) than at all other spacings. Virginia pine survival was highest at the 9x9 foot spacing (70.23%) but was not significantly higher than at all other spacings.

Thirty year survival was lowest at the 6x6 foot spacing across all species (Table 3). Virginia pine had the poorest survival with only 342 spa, or 29.26%, present. Survival ranged from 40.2%, 43.1%, and 44.6% for white, loblolly and shortleaf pines, respectively, at the 6x6 foot spacing. White pine survival increased, although at a decreasing rate, as spacing increased with an 80.8% survival at the 15x15 foot spacing. Loblolly pine and Virginia pine survival was highest at the 12x12 foot spacings. Notably, loblolly pine had a 73% survival at this spacing, only slightly less than white pine's 74.5% at the same spacing. No trend was present in the shortleaf pine survival.

Tree Dimensions at 22 Years

Spacing is just as crucial for tree dimensions as survival for optimizing a return on investment. Total height (feet), DBH (inches), total stemwood volume (ft^3) and value ($) were calculated by tree for 22 years after establishment and analyzed.

Height. The main effects of spacing and species on height growth were large. Height at the 9x9, 12x12, and 15x15 foot spacings (58, 58 and 59 feet, respectively) was significantly greater than at the 6x6 foot spacing at 56 feet across all species (Table 4).

Table 4. Mean tree dimensions by species and spacing 22 years after establishment for the species-spacing comparison study at Tullahoma, TN.

Species	Tree Dimension	Spacing (feet) 6x6	9x9	12x12	15x15	Mean
Loblolly Pine	Height (ft)	58fg[1]	61ce	63bcd	61ce	61a[2]
	DBH (in)	7.4ef	8.6cd	9.9b	11.0a	9.2a
	Vol (ft^3)	10.2de	13.7c	18.3b	23.2a	16.4a
	Value ($)	7.63efg	12.11d	19.14c	26.39b	16.32b
Shortleaf Pine	Height (ft)	51j	53hi	54hi	55hi	53b
	DBH (in)	6.2g	7.0f	8.2de	8.3d	7.4b
	Vol (ft^3)	6.8fg	8.8e	12.3cd	12.7c	10.1b
	Value ($)	4.79gh	6.18fgh	10.52de	10.82de	8.08c
Virginia Pine	Height (ft)	54hi	56gh	55hi	54ij	55b
	DBH (in)	5.8g	7.3f	8.6cd	9.1c	7.7b
	Vol (ft^3)	5.7g	9.0ef	12.2cd	13.1c	10.0b
	Value ($)	3.79h	6.29fgh	10.52de	11.84d	8.11c
Eastern White Pine	Height (ft)	61c	63b	62bc	66a	63a
	DBH (in)	7.5ef	8.8cd	9.8b	11.3a	9.3a
	Vol (ft^3)	9.6e	14.0c	17.5b	23.3a	16.1a
	Value ($)	8.82def	17.40c	25.08b	36.13a	21.86a
Mean	Height (ft)	56b[3]	58a	58a	59a	58
	DBH (in)	6.7d	7.9c	9.1b	9.9a	8.4
	Vol (ft^3)	8.1d	11.4c	15.1b	18.1a	13.2
	Value ($)	6.26d	10.50c	16.32b	21.30a	13.59

[1] Significant differences among spacings and species indicated by different letters.
[2] Significant differences among species indicated by different letters.
[3] Significant differences among spacings indicated by different letters.

Shortleaf and Virginia pines were not significantly different in height at 53 and 55 feet but were significantly shorter than loblolly pine at 61 feet and white pine at 63 feet.

White pine at 22 years ranged from 61 feet at the 6x6 foot spacing to 66 feet for the 15x15 foot spacing (Table 4). The 15x15 foot spacing was significantly taller than all other spacings. Loblolly pine was similar at the 9x9, 12x12 and 15x15 foot spacings, with heights of 61, 63 and 61 feet. The heights at these spacings were significantly taller than at the 6x6 foot spacing (58 ft). Shortleaf pine height was tallest at the 15x15 foot spacing (55 ft) but was not significantly taller then at the 12x12 foot spacing (54 ft) and the 9x9 foot spacing (53 ft). Virginia pine was tallest at the 9x9 foot spacing (56 ft) but was not significantly taller than at the 12x12 foot spacing (55 ft), the 6x6 foot spacing (54 ft) and the 15x15 foot spacing (54ft).

Tree DBH. Significant differences in mean tree diameter at breast height (DBH) for the species and spacing main effects as well as their interaction were detected. Mean DBH increased as spacing increased, ranging from 6.7 inches at the 6x6 spacing to 9.9 inches at the 15x15 foot spacing (Table 4). Loblolly pine and white pine at 9.2 and 9.3 inches, respectively, were significantly larger than shortleaf and Virginia pines at 7.4 inches and 7.7 inches, respectively.

DBH increased with spacing for each of the four species. White pine and loblolly pine had similar DBH's of 11.3 and 11.0 inches at the 15x15 foot spacing (Table 4). These DBH's were significantly larger than the 12x12 foot spacing with DBH's of 9.8 and 9.9 inches for the respective species.

Tree Volume. The main effects of species and spacing as well as their interaction are significant. Each three foot increase in spacing resulted in a significant increase in the volume per tree without regard to species (Table 4). Across all spacings, white pine and loblolly pine had similar volumes per tree at 16.1 ft^3 and 16.4 ft^3, respectively, which was significantly greater than shortleaf pine at 10.1 ft^3 and Virginia pine at 10.0 ft^3.

All four species showed significant increases in volume per tree with increased spacing. White pine (23.3 ft^3) and loblolly pine (23.2 ft^3) achieved the largest volumes at the 15x15 foot spacing and were significantly larger then the next largest volumes achieved by loblolly pine and white pine at the 12x12 foot spacing with volumes of 18.3 ft^3 and 17.5 ft^3 per tree, respectively (Table 4). Shortleaf pine ranged from 6.8 ft^3 at the 6x6 foot spacing to 12.7 ft^3 at the 15x15 foot spacing. Virginia pine mean volume per tree ranged from 5.7 ft^3 at the 6x6 foot spacing to 13.1 ft^3 at the 15x15 foot spacing.

Tree Value. The value of each tree was significantly influenced by the main effects of species and spacing as well as their interaction. Over all spacings, white pine value per tree ($21.86) was significantly higher than loblolly pine ($16.32) (Table 4). White pine and loblolly pine were significantly higher then Virginia pine and shortleaf pine at $8.11 and $8.08, respectively. Value per tree had significant increases with each increase in spacing both over all four species and for each species individually. The largest mean value per tree was $36.13 achieved by white pine planted at the 15x15 foot spacing. The value decreased significantly as planting density increased. Loblolly pine at the 15x15 foot spacing had a mean value of $26.39 per tree.

Tree Dimensions at 30 Years

Spacing is just as crucial for tree dimensions as survival for optimizing a return on investment. Total height (feet), DBH (inches), total stemwood volume (ft^3) and value ($) were calculated by tree for 30 years after establishment and analyzed.

Height. The main effects of spacing and species on height growth were significant. The 6x6 and 9x9 foot spacing were significantly taller than the 12x12 and 15x15 foot spacing across all species at 68 feet as compared with 66 and 67 feet, respectively (Table 5). Shortleaf and Virginia pines were not significantly different in height at 59 and 60 feet, while loblolly pine at 72 feet and white pine at 78 feet were different from each other and from the other two species.

White pine was tallest across all spacings. At 30 years it ranged from 77 feet for the 12x12 foot spacing to 79 feet for the 15x15 foot spacing (Table 5). The 15x15 foot spacing was significantly taller than the 12x12 foot spacing but neither was significantly different than the 6x6 foot spacing at 78 feet or the 9x9 foot spacing at 79 feet. Loblolly pine was similar at the 6x6 and 15x15 foot spacing, both 73 feet, and significantly different from the 9x9 and 12x12 foot spacing, both 70 feet. Shortleaf pine at the 6x6 and 9x9 foot spacing (60 ft and 61 ft, respectively) was significantly taller than the 12x12 and 15x15 foot spacing (58 ft and 57 ft, respectively). Virginia pine at the 9x9 foot spacing (63 ft) was significantly taller than at the 12x12 foot spacing (59 ft) and the 15x15 foot spacing (57 ft) while the 15x15 foot spacing was significantly shorter than all other spacings; the

Table 5. Mean tree dimensions by species and spacing 30 years after establishment for the species-spacing comparison study at Tullahoma, TN.

Species	Tree Dimension	Spacing (feet) 6x6	9x9	12x12	15x15	Mean
Loblolly Pine	Height (ft)	73c[1]	70d	70d	73c	72b[2]
	DBH (in)	9.0gh	10.1ef	11.7bc	13.5a	11.1a
	Vol (ft^3)	17.2ef	21.1d	27.2c	38.4a	26.0a
	Value ($)	16.13fgh	22.36e	31.05d	45.70b	28.81b
Shortleaf Pine	Height (ft)	60f	61ef	58gh	57gh	59c
	DBH (in)	7.5i	8.6h	9.5fg	9.8fg	8.9b
	Vol (ft^3)	11.2hi	14.4fg	17.4def	17.6de	15.1b
	Value ($)	8.49i	12.33ghi	17.79efg	17.96ef	14.14c
Virginia Pine	Height (ft)	62ef	63e	59fg	57h	60c
	DBH (in)	6.9i	8.6h	10.0f	10.6de	9.0b
	Vol (ft^3)	8.8i	13.1gh	16.8ef	18.2de	14.2b
	Value ($)	6.45i	10.78hi	17.20efg	19.59ef	13.51c
Eastern White Pine	Height (ft)	78ab	79ab	77b	79a	78a
	DBH (in)	9.3fgh	11.0cd	12.2b	13.9a	11.6a
	Vol (ft^3)	18.2def	25.1c	31.4b	40.4a	28.8a
	Value ($)	22.90e	37.73c	49.86b	66.18a	44.17a
Mean	Height (ft)	68a[3]	68a	66b	67b	67
	DBH (in)	8.2d	9.6c	10.9b	12.0a	10.2
	Vol (ft^3)	13.8d	18.4c	23.2b	28.7a	21.0
	Value ($)	13.49d	20.80c	28.98b	37.36a	25.16

[1] Significant differences among spacings and species indicated by different letters.
[2] Significant differences among species indicated by different letters.
[3] Significant differences among spacings indicated by different letters.

6x6 foot spacing (62 ft) was not significantly different from the 9x9 foot spacing and the 12x12 foot spacing.

Tree DBH. Mean tree diameter at breast height demonstrated significance for the species and spacing main effects as well as their interaction. Over all species, mean DBH increased as spacing increased significantly, ranging from 8.2 inches at the 6x6 spacing to 12.0 inches at the 15x15 foot spacing (Table 5). Loblolly pine and white pine were not significantly different at 11.1 and 11.6 inches, respectively, but were significantly different from shortleaf pine and Virginia pine at 8.8 inches and 9.0 inches, respectively.

Tree DBH increased significantly with wider spacing for all four species. White pine and loblolly pine had similar DBH's of 13.9 and 13.5 inches at the 15x15 foot spacing and at the 12x12 foot spacing with DBH's of 12.2 and 11.7 inches (Table 5). White pine and loblolly pine DBH's at the 9x9 foot spacing are 11.0 inches and 10.1 inches and 9.3 inches and 9.0 inches, respectively, at the 6x6 foot spacing.

Tree Volume. The main effects of species and spacing as well as their interaction are significant. Each three foot increase in spacing resulted in a significant increase in the volume per tree without regard to species (Table 5). White pine and loblolly pine had similar volumes per tree at 28.8 ft^3 and 26.0 ft^3, respectively, averaged across spacing.

Individual tree volume increased significantly with wider spacings for all four species. White pine and loblolly pine at the 15x15 foot spacing achieved the largest volumes: 40.4 and 38.4 ft^3, respectively (Table 5). The next largest was the white pine at a 12x12 foot spacing with a volume of 31.4 ft^3. Loblolly pine at a 12x12 foot spacing and white pine at the 9x9 foot spacing were similar with volumes of 27.2 and 25.1 ft^3 per tree, respectively.

Tree Value. The value of each tree was significantly influenced by the main effects of species and spacing as well as their interaction. Value per tree over all spacings was highest for white pine ($44.17), followed by loblolly pine ($28.81), shortleaf pine ($14.14) and then Virginia pine ($13.51), (Table 5).

Value per tree increased significantly as spacing increased for all four species. The largest mean value per tree was $66.18 achieved by the white pine planted at the 15x15 foot spacing (Table 5). White pine at the 12x12 foot spacing and loblolly pine at the 15x15 foot spacing were similar with mean values of $49.86 and $45.70 per tree, respectively. White pine at the 9x9 foot spacing is valued at $37.73 per tree. Loblolly pine at the 12x12 foot spacing had a mean value of $31.05 per tree. Shortleaf pine and Virginia pine at the 6x6 spacing had the smallest mean values per tree at $8.49 and $6.45, respectively.

Stand Dimensions at 22 Years

The effects of spacing on the stand level variables are the combined effects that spacing has on survival and tree dimensions. Stand basal area (ft^2/acre), stand volume (ft^3/acre) and value ($/acre) were calculated for each plot at 22 years and analyzed.

Stand Basal Area. Stand basal area significantly decreased with every increase in planting increment. Basal areas ranged from 179 ft^2/acre at the 6x6 foot spacing to 79 ft^2/acre at the 15x15 foot spacing (Table 6).

Table 6. Mean stand dimensions by species and spacing at 22 years after establishment for the species-spacing comparison study at Tullahoma, TN.

Species	Stand Dimension	Spacing (feet) 6x6	9x9	12x12	15x15	Mean
Loblolly Pine	BA (ft^2/ac)	208a[1]	142cde	128def	90h	142b[2]
	Vol (ft^3/ac)	6656.3a	4643.0c	4204.9cd	2914.8fg	4604.8a
	Val ($/ac)	4923.18cd	4099.71de	4401.14d	3321.92f	4186.49b
Shortleaf Pine	BA (ft^2/ac)	145cd	102gh	59i	43i	88d
	Vol (ft^3/ac)	4441.8cd	3206.9f	1860.0hi	1330.6i	2709.8b
	Val ($/ac)	3123.53efg	2240.13hij	1594.00ijk	1143.73k	2025.35c
Virginia Pine	BA (ft^2/ac)	153c	114fg	86h	58i	103c
	Vol (ft^3/ac)	4528.9cd	3390.4ef	2482.8gh	1627.5l	3007.4b
	Val ($/ac)	3026.54fgh	2373.77ghi	2135.57ij	1479.87jk	2253.94c
Eastern White Pine	BA (ft^2/ac)	210a	187b	142cd	126ef	166a
	Vol (ft^3/ac)	6139.2ab	5679.7b	4270.4cd	3943.1de	5008.1a
	Val ($/ac)	5635.14bc	7070.18a	6132.44b	6118.99b	6239.19a
Mean	BA (ft^2/ac)	179a[3]	136b	104c	79d	125
	Vol (ft^3/ac)	5441.6a	4230.0b	3204.5c	2454.0d	3839.3
	Val ($/ac)	4177.10a	3945.95ab	3565.79b	3016.13c	3681.61

[1] Significant differences among spacings and species indicated by different letters.
[2] Significant differences among species indicated by different letters.
[3] Significant differences among spacings indicated by different letters.

Eastern white pine, with a basal area of 166 ft^2/acre averaged over all spacings (Table 6) was significantly higher than all other species. Loblolly pine's basal area of 142 ft^2/acre was significantly higher than shortleaf pine (88 ft^2/acre) and Virginia pine (103 ft^2/acre), which were not significantly different.

White pine had the highest basal area for each spacing ranging from 210 ft^2/acre at the 6x6 foot spacing to 126 ft^2/acre at the 15x15 foot spacing (Table 6). Loblolly pine had the next highest basal area ranging from 208 ft^2/acre at the 6x6 foot spacing to 90 ft^2/acre at the 15x15 foot spacing. Stand basal area decreased significantly with increased spacing for all species. White pine and loblolly pine did not have significantly different basal areas at the 6x6 foot spacing. White pine had a significantly higher basal area at the 9x9 foot spacing than any other species at that spacing. White pine and loblolly pine showed no significant differences at the 12x12 foot spacing but white pine was significantly larger than loblolly at the 15x15 foot spacing.

<u>Stand Volume.</u> The 6x6 foot spacing had a volume of 5441.6 ft^3/acre (Table 6), significantly greater than all other spacings. Stand volume at the 9x9 foot spacing at 4230.0 ft^3/acre, the 12x12 foot spacing at 3204.5 ft^3/acre and the 15x15 spacing at 2454.0 ft^3/acre were all significantly different.

Eastern white pine and loblolly pine showed no significant difference in average volume at 5008.1 ft^3/acre and 4604.8 ft^3/acre, respectively (Table 6). These were significantly greater than shortleaf and Virginia pines.

Loblolly pine at the 6x6 foot spacing achieved the greatest volume at 6656.3 ft^3/acre but was not significantly greater than white pine at the 6x6 foot spacing (6139.2

ft^3/acre) (Table 6). White pine volume at the 9x9 foot spacing (5679.7 ft^3/acre) was significantly greater than all other species at the 9x9 foot spacing. Stand volume decreased significantly with increasing spacing for each species. There was no significant difference in volumes between white pine at the 6x6 foot spacing and the 9x9 foot spacing or between the 12x12 foot spacing and the 15x15 foot spacing.

Stand Value. The 6x6 foot spacing had a significantly higher value (4177.10 $/acre) than the 12x12 and 15x15 foot spacings but was not significantly different than the value at the 9x9 foot spacing (3945.95 $/acre) (Table 6). The 15x15 foot spacing had significantly less value than the other spacings.

Eastern white pine had significantly greater value at $6239.19/acre than all other species over all spacings (Table 6). Loblolly pine was valued at $4186.49/acre which was significantly greater than shortleaf and Virginia which showed no significant differences.

White pine had significantly greater value at the 9x9 foot spacing, $7070.18/acre (Table 7), than at any other spacing or any other species. White pine at all other spacings showed no significant differences in value but only the 6x6 foot spacing was not significantly greater than all other species. White pine at this spacing had a value of $5635.14/acre which was not significantly greater than loblolly at the same spacing valued at $4923.18/acre. Value decreased significantly with increased spacing for all species except white pine. White pine value for the 9x9 foot spacing was greater than for the other three spacings.

Stand Dimensions at 30 Years

The effects of spacing on the dimensions of a stand are the combined effects that spacing has on survival and tree dimensions. Stand basal area (ft^2/acre), stand volume (ft^3/acre) and value ($/acre) were calculated for each plot at 30 years and analyzed.

Stand Basal Area. The 6x6 foot spacing had significantly higher basal area than all other spacings. Basal area significantly decreased with every increase in planting increment.

Eastern white pine had significantly higher basal area (217 ft^2/acre) than all other species (Table 7). Loblolly pine had a mean basal area of 190 ft^2/acre which was significantly greater than shortleaf and Virginia pines which were not significantly different.

Stand basal area decreased significantly with increasing spacing except in Virginia pine. Virginia pine basal area decreased with wider spacings from the 9x9 foot spacing with the 6x6 foot spacing being not significantly different from the 12x12 foot and the 15x15 foot spacing.

White pine had the highest basal area at a 6x6 foot spacing with 247 ft^2/acre but was not significantly higher than either white pine at the 9x9 foot spacing or loblolly pine at the 6x6 foot spacing and significantly higher (170 ft^2/acre) at the 15x15 foot spacing (Table 7). Loblolly pine had the next highest basal area per acre ranging from 242 ft^2/acre at the 6x6 foot spacing to 129 ft^2/acre at the 15x15 foot spacing.

Table 7. Mean stand dimensions by species and spacing at 30 years after establishment for the species-spacing comparison study at Tullahoma, TN.

Species	Stand Dimension	Spacing (feet) 6x6	9x9	12x12	15x15	Mean
Loblolly Pine	BA (ft^2/ac)	237a[1]	179c	169c	129d	179b[2]
	Vol (ft^3/ac)	8819.7a	6471.1bc	6014.4c	4807.2d	6528.1b
	Val ($/ac)	8244.72c	6856.79de	6862.66d	5715.05ef	6919.81b
Shortleaf Pine	BA (ft^2/ac)	173c	126de	73gh	54h	107c
	Vol (ft^3/ac)	5979.9c	4369.4d	2452.1ef	1784.7f	3646.5c
	Val ($/ac)	4530.07fg	3736.28gh	2502.98hij	1829.57j	3149.72c
Virginia Pine	BA (ft^2/ac)	96fg	128d	106ef	72gh	100c
	Vol (ft^3/ac)	3056.3e	4045.2d	3173.0e	2117.8f	3098.1c
	Val ($/ac)	2222.85hij	3316.54ghi	3248.80ghij	2275.38ij	2765.89c
Eastern White Pine	BA (ft^2/ac)	247a	239a	206b	177c	217a
	Vol (ft^3/ac)	8908.1a	8517.7a	7097.0b	6347.3c	7717.5a
	Val ($/ac)	11217.23b	12798.08a	11289.59b	10404.21b	11427.28a
Mean	BA (ft^2/ac)	188a[3]	168b	138c	108d	151
	Vol (ft^3/ac)	6691.0a	5850.8b	4684.1c	3764.3d	5227
	Val ($/ac)	6553.72ab	6676.92a	5976.01b	5056.05c	6000.94

[1] Significant differences among spacings and species indicated by different letters.
[2] Significant differences among species indicated by different letters.
[3] Significant differences among spacings indicated by different letters.

Stand Volume. Volume at the 6x6 foot spacing, 6691.0 ft^3/acre, was significantly larger than volume on all other spacings (Table 7). There was a significant decrease in volume for every increase in planting increment.

Eastern white pine volume of 7717.5 ft^3/acre was significantly larger than all other species (Table 7). Loblolly pine volume of 6528.1 ft^3/acre is significantly larger than both shortleaf pine and Virginia pine which are not significantly different.

White pine at the 6x6 foot spacing achieved the greatest volume at 8,908.1 ft^3/acre but was not significantly different than loblolly pine volume at the 6x6 foot spacing at 8819.7 ft^3/acre, or white pine volume at the 9x9 foot spacing at 8,517.7 ft^3/acre (Table 7).

Stand Value. The 9x9 foot spacing had the highest value at $6676.92/acre but was not significantly greater than the value at the 6x6 spacing of $6553.72/acre (Table 7). The value at the 15x15 foot spacing was significantly less than all other spacings.

White pine had a significantly higher value at $11427.28/acre than all other species (Table 7). Loblolly pine at $6919.81/acre was significantly higher in value than both shortleaf and Virginia pines at $3149.72/acre and $2765.89/acre, respectively.

White pine at the 9x9 foot spacing at $12,798.08/acre was significantly higher in value than at any other spacing or any other species (Table 7). White pine at all other spacings were significantly higher in value than any other species. Loblolly pine was significantly more valuable with $8244.72/acre at the 6x6 foot spacing than at any spacing and shortleaf pine or Virginia pine.

CHAPTER VI

DISCUSSION

The species and spacing comparison study on the Highland Rim Forestry Experiment Station revealed significant differences in survival, individual tree characteristics and stand level characteristics across the four species and four spacings at 22 and 30 years from establishment.

Spacing affected survival in only the highest planting density at 22 and 30 years. These results are in agreement with Hansbrough's (1968) and Balmer's et al. (1975) comparison of loblolly pine at various planting densities and Campbell and Mann's (1974) study of white pine. White pine had the highest survival of all species though there are no significant differences between species at 22 or at 30 years. Shortleaf pine had lower survival at both 22 and 30 years than loblolly pine, which was in disagreement with Williston (1959). Shortleaf pine competes best on rocky, dry upland sites. The hardwood in growth may have some affect on shortleaf pine survival on this level and more mesic site. The fragipan located on the site may also have inhibited proper root development. White pine had the highest overall survival at the widest spacing, 87% at 22 years and 81% at 30 years.

Height was significantly affected by spacing only at the narrowest spacing at 22 years, which is in agreement with McClurkin (1976). At 30 years, this effect was lost and instead height at the 12x12 foot spacing and the 15x15 foot spacing was significantly less than at the 6x6 foot spacing and the 9x9 foot spacing which was in contrast to the findings of Balmer et al. (1975), Bramble et al. (1949) and Hansbrough (1968). This trend is present only when the affect of spacing on height is considered regardless of species. Within species, no trend is present which agrees with the findings of Balmer et al. (1975), Bramble et al. (1949) and Hansbrough (1968). White pine and loblolly pine were significantly taller than shortleaf pine and Virginia pine at 22 years. This is in agreement with results of Williston (1959) and Burton (1964). At 30 years, white pine was significantly taller than all other species.

It is generally accepted that diameter growth significantly increases at wider spacings; this was again demonstrated with this study at 22 and 30 years. White pine and loblolly pine diameters are greater than shortleaf pine and Virginia pine at 22 and 30 years. The vigorous height and diameter growth of loblolly pine and white pine at 22 and 30 years is in agreement with Burton (1964) and Loftus (1974).

Stand basal area significantly increased with each decrease in spacing. Stand basal area increased within each spacing from the 22 year measurement to the 30 year measurement. White pine had the highest stand basal area at 22 years and 30 years. Each species showed an increasing basal area over time. Stand volume is greatest at the smallest spacing at both 22 and 30 years, however, the stand value is greatest at the 9x9 foot spacing at 30 years. This indicates the greater merchantable volume at the 9x9 foot spacing and disagrees with McClurkin (1976). Virginia pine and white pine are the only two species that had greater value at the 9x9 foot spacing than the 6x6 foot spacing. Virginia pine had a dramatic decrease in stand basal area, stand volume and stand value at the 6x6 foot spacing from the 22-year to the 30-year measurements. This decline is due to the mortality from the 22 year measurement to the 30 year measurement. Wind throw on two Virginia pine subplots was a large reason survival decreased from 65.36% at 22 years to 29.56% at 30 years. The increase in sawtimber from the 6x6 foot spacing to the 9x9 foot spacing along with the dramatic difference in value between pulpwood and sawtimber in white pine would account for the higher value at the 9x9 foot spacing in white pine. Taking into account the windthrow and the differences in species, McClurkin's (1976) reported results on loblolly pine alone agrees with the results of loblolly pine in this study.

White pine and loblolly pine grew better than shortleaf pine and Virginia pine. This may be in part due to white pine and loblolly pine's ability to grow well on a variety of site conditions. These results suggest that the fragipan present at this site did not hinder vigorous white pine and loblolly pine growth. In general, white pine and loblolly pine demonstrate greater height and diameter growth then shortleaf pine and Virginia pine, as there are no significant differences in survival among species.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

It is the author's recommendation, based on the results of this study, that white pine and loblolly pine are capable of being successfully grown on the Eastern Highland Rim of Tennessee. These two species had better survival, growth, and higher value than shortleaf pine and Virginia pine.

Growth was greatest in white pine followed by loblolly pine. White pine has significantly greater height growth than all other species. White pine and loblolly pine have larger diameters than Virginia pine and shortleaf pine. White pine and loblolly pine had the highest stand basal areas, exceeding 240 square feet per acre at the 6x6 foot spacing. In the last eight growing seasons, white pine basal area has become greater than that of loblolly pine. White pine had the greatest volume growth at the stand level across all spacings followed by loblolly pine. This was also reflected in the stand volume where white pine proved to have higher value than all other species followed by loblolly pine.

Based on these results, white pine should be the species of choice. However, the author is aware that this study assumed an availability of all markets for this area as well as equal value given to white pine pulpwood as that given the other three pine species. This allowed for possible market availability of pulpwood-sized white pine such as a treated post market. Another assumption worthy of note is that of an $80/MBF difference in favor of white pine over yellow pine sawtimber. With all assumptions intact, white pine planted at a 6x6 foot or a 9x9 foot spacing is recommended. If the above assumptions depart from reality, loblolly pine planted at a 6x6 spacing offers a viable alternative.

If trends over time continue and mortality levels the number of stems per acre across initial planting densities, at what age will the effect of initial planting density be lost for each species? This assumes that stocking and growth will reach some equilibrium for each species. It should be noted that due to mortality, growth and yield of the lower initial planting densities may overtake that of the higher initial planting densities as is already demonstrated with the stand basal area, stand volume and stand value measurements of Virginia pine across all initial spacing. At what point will the volume lost to tree mortality become greater than the volume increase from tree growth at each spacing for each species? These questions point to the need for continuing measurements taken at regular intervals in the future.

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APPENDIX

Figure A-1. Form-class segmented-profile model equation for estimating stem volume (V) between any two heights.

$$V = 0.005454154\ [\ I_1\ D^2\ \{(\ 1\text{-}GW\ )\ (\ U_1\text{-}L_1) + W\ ((\ 1\text{-}L_1/H\ )^r\ (\ H\text{-}L_1) -$$

$$(\ 1\text{-}U_1/H\ )^r\ (\ H\text{-}U_1\ ))\ /\ (\ r\text{+}1\ )\}$$

$$+\ I_2\ I_3\ \{\ T\ (\ U_2\text{-}L_2\ ) + Z\ ((\ 1\text{-}L_2/H\ )^p\ (\ H\text{-}L_2\ ) -$$

$$(\ 1\text{-}U_2/H\ )^p\ (\ H\text{-}U_2\ ))\ /\ (\ p\text{+}1\ )\}$$

$$+\ I_4\ F_2\ \{\ b\ (\ U_3\text{-}L_3\ ) - b\ ((\ U_3\text{-}17.3\ )^2 - (\ L_3\text{-}17.3\ )^2\ )\ /\ (\ H\text{-}17.3\ ) +$$

$$(\ b/3\ )\ ((\ U_3\text{-}17.3\ )^3 - (\ L_3\text{-}17.3\ )^3\ )\ /\ (\ H\text{-}17.3\ )^2 +$$

$$I_5\ (\ 1/3\ )\ ((\ 1\text{-}b\ )\ /\ a^2\ )\ (\ a\ (\ H\text{-}17.3\ ) - (\ L_3\text{-}17.3\ ))^3\ /\ (\ H\text{-}17.3\ )^2 -$$

$$I_6\ (\ 1/3\ )\ ((\ 1\text{-}b\ )\ /\ a^2\ )\ (\ a\ (\ H\text{-}17.3\ ) - (\ U_3\text{-}17.3\ ))^3\ /\ (H\text{-}17.3\ )^2\ \}]$$

Note: For a complete listing of basic symbol, combined variable, indicator variable and coefficient definitions see Clark et al. 1991.

Figure A-2. Form-class segmented-profile model equation for estimating stem volume (V) between any two heights from DBH, diameter at 17.3 feet, and height to a fixed-DOB top.

$$V = 0.005454154\ [\ I_1\ D^2\ \{(\ 1\text{-}GW\ )\ (\ U_1\text{-}L_1)\ +\ W\ ((\ 1\text{-}L_1/H_x\ )^r\ (\ H_x\text{-}L_1)\ -$$

$$(\ 1\text{-}U_1/H_x\ )^r\ (\ H_x\text{-}U_1\ ))\ /\ (\ r+1\ )\}$$

$$+\ I_2\ I_3\ \{\ T\ (\ U_2\text{-}L_2\ )\ +\ Z\ ((\ 1\text{-}L_2/H_x\ )^p\ (\ H_x\text{-}L_2\ )\ -$$

$$(\ 1\text{-}U_2/H_x\ )^p\ (\ H_x\text{-}U_2\ ))\ /\ (\ p+1\ )\}$$

$$+\ I_4\ \{N\ (\ U_3\text{-}L_3\ )\ +\ R\ ((\ 1\text{-}L_3/H_x\ )^q\ (\ H_x\text{-}L_3\ )\ -$$

$$(\ 1\text{-}U_3/H_x\ )^q\ (\ H_x\text{-}U_3\ ))\ /\ (\ q+1\ )\}]$$

Note: For a complete listing of basic symbol, combined variable, indicator variable and coefficient definitions see Clark et al. 1991.

Table A-1. Survival mean square values from the analysis of variance for species and spacing at 22 and 30 years from establishment for the species-spacing comparison study at Tullahoma, TN.

		Mean Square Values	
Source	DF	Survival, 22 years	Survival, 30 years
Species	3	4.62	3.84
Block	3	7.10	4.26
Error A	9	1.88	1.59
Spacing	3	2.60	10.46
Spacing*Species	9	1.60	1.33
Error B	36	0.21	0.22
Total	63		

Table A-2. Tree dimension mean square values from the analysis of variance for species and spacing at 22 and 30 years from establishment on the species-spacing comparison study at Tullahoma, TN.

		Mean Square Values							
		Height		DBH		Volume		Value	
Source	DF	22 years	30 years	22 years	30 years	22 years	30 years	22 years	30 years
Species	3	11197.26	39880.54	645.63	1041.64	8087.42*	29941.27	31105.62	121330.16
Block	3	4382.98	2184.93	57.55	74.69	251.04	2782.58	1198.11	7151.74
Error A	9	542.70	287.16	30.99	36.54	319.79	595.39	590.53	1299.48*
Spacing	3	789.81	512.57	1033.65	1118.37	10190.72	18994.28	24701.18	50537.65
Spacing*Species	9	371.25	436.51	16.21*	30.53	411.3	1618.54	2354.55	5133.13
Error B	36	68.61	60.67	4.74	5.68	51.56	130.06	141.28	378.70
Total	63								

* Indicates significance at the .05 probability level.

Table A-3. Stand dimension mean square values from the analysis of variance for species and spacing at 22 and 30 years from establishment on the species-spacing comparison study at Tullahoma, TN.

		Mean Square Values					
		Basal Area		Volume		Value	
Source	DF	22 years	30 years	22 years	30 years	22 years	30 years
Species	3	572341.55	1293493.77	586139610.94	1993543024.92	2097445971.39	7326545564.01
Block	3	104021.1	117889.17	42527092.46	208054003.02	130524898.19	492310950.71
Error A	9	12487.73*	12474.75*	13714977.51*	12778310.91*	28381135.70*	44249346.66*
Spacing	3	929765.1	588830.93	840064764.50	774877627.01	129743162.84	299290200.37
Spacing*Species	9	10122.06*	37414.39	14165747.22*	46241597.38	37829601.26*	49892125.47*
Error B	36	4036.54	5226.10	4329051.65	7375064.74	10495259.69	22286008.56
Total	63						

* Indicates significance at the .05 probability level

TABLE A4. Number of Stems per Acre by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	617	570	617	855	665
	9x9	303	404	370	269	337
	12x12	225	231	237	231	231
	15x15	126	84	160	143	126
Shortleaf Pine	6x6	712	380	760	807	665
	9x9	258	359	415	415	362
	12x12	49	122	164	266	150
	15x15	35	52	163	161	104
Virginia Pine	6x6	831	499	949	762	791
	9x9	314	359	426	415	378
	12x12	200	200	192	219	203
	15x15	90	101	146	161	125
White Pine	6x6	712	546	736	570	641
	9x9	381	438	449	359	407
	12x12	261	225	267	225	244
	15x15	174	153	177	174	169

TABLE A5. Percent Survival by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	51.0	47.1	51.0	70.6	54.9
	9x9	56.3	75.0	68.8	50.0	62.5
	12x12	74.0	76.0	78.0	76.0	76.0
	15x15	65.0	43.1	82.1	73.4	65.0
Shortleaf Pine	6x6	58.8	31.4	62.7	66.7	54.9
	9x9	48.0	66.7	77.1	77.1	67.2
	12x12	16.0	40.0	54.0	87.8	49.4
	15x15	17.9	26.8	83.9	82.8	53.2
Virginia Pine	6x6	68.6	41.2	78.4	63.0	65.4
	9x9	58.3	66.7	79.2	77.1	70.2
	12x12	66.0	66.0	63.3	72.0	66.9
	15x15	46.4	51.8	75.0	82.8	64.4
White Pine	6x6	58.8	45.1	60.8	47.1	52.9
	9x9	70.1	81.3	83.3	66.7	75.5
	12x12	86.0	74.0	88.0	74.0	80.5
	15x15	89.3	78.6	91.1	89.3	87.1
Total		58.2	56.9	73.5	72.3	65.4

TABLE A6. Mean Height (Feet) by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	48	58	61	64	58
	9x9	60	57	63	63	61
	12x12	59	59	65	68	63
	15x15	59	62	67	56	61
Shortleaf Pine	6x6	46	48	57	52	51
	9x9	46	52	60	56	54
	12x12	39	58	56	58	56
	15x15	39	50	60	62	58
Virginia Pine	6x6	51	48	57	57	54
	9x9	50	57	59	58	57
	12x12	52	54	56	58	55
	15x15	51	51	55	57	54
White Pine	6x6	57	63	61	62	60
	9x9	59	61	64	67	63
	12x12	61	58	61	66	62
	15x15	63	67	66	69	66

TABLE A7. Mean Diameter at Breast Height (Inches) by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
	6x6	6.8	7.8	7.3	7.3	7.3
Loblolly	9x9	9.4	8.2	8.7	8.3	8.6
Pine	12x12	10.4	9.4	10.4	9.4	9.9
	15x15	12.3	12.5	11.6	8.5	11.0
	6x6	6.1	7.4	6.4	5.2	6.1
Shortleaf	9x9	7.2	7.7	7.1	6.1	7.0
Pine	12x12	6.7	9.6	7.5	8.0	8.1
	15x15	7.2	7.9	8.6	8.2	8.2
	6x6	5.9	5.2	6.0	5.6	5.8
Virginia	9x9	7.4	7.2	7.5	7.1	7.3
Pine	12x12	8.5	8.7	8.9	8.5	8.6
	15x15	8.9	9.7	9.1	8.7	9.1
	6x6	7.4	8.4	7.1	7.1	7.5
White	9x9	8.9	8.6	8.1	9.7	8.7
Pine	12x12	10.6	9.5	9.7	9.5	9.8
	15x15	11.0	11.5	11.3	11.3	11.3

TABLE A8. Mean Value ($) per Tree by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
	6x6	5.64	9.20	7.46	7.30	7.36
Loblolly	9x9	15.64	9.47	12.38	12.52	12.27
Pine	12x12	20.62	16.55	22.37	16.95	19.14
	15x15	30.74	32.88	29.14	15.38	26.28
	6x6	3.83	7.58	5.18	3.40	4.62
Shortleaf	9x9	5.44	7.30	6.82	5.24	6.24
Pine	12x12	4.13	16.19	8.20	10.63	10.57
	15x15	5.83	9.25	11.89	11.14	10.77
	6x6	3.92	3.03	4.26	3.48	3.86
Virginia	9x9	5.90	6.40	6.66	6.09	6.28
Pine	12x12	10.90	9.79	12.20	9.32	10.50
	15x15	10.93	13.94	11.99	10.84	11.78
	6x6	8.72	14.36	6.18	6.64	8.73
White	9x9	17.27	18.65	12.91	21.66	17.40
Pine	12x12	28.04	25.71	23.58	22.55	25.04
	15x15	35.31	38.45	35.90	34.94	36.08

TABLE A9. Basal Area (Square Feet per Acre) by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
	6x6	173.72	208.67	186.82	259.76	207.35
Loblolly	9x9	152.95	151.96	159.46	109.22	143.61
Pine	12x12	136.97	117.54	144.69	114.71	128.48
	15x15	106.80	72.49	119.50	63.46	88.69
	6x6	150.80	119.85	174.42	130.50	143.94
Shortleaf	9x9	74.43	119.86	119.36	92.36	101.57
Pine	12x12	12.45	62.93	53.18	98.94	56.79
	15x15	10.33	18.55	67.36	61.52	39.92
	6x6	168.43	79.81	197.34	132.03	153.70
Virginia	9x9	97.27	106.39	135.06	118.58	114.21
Pine	12x12	84.34	84.74	86.52	87.87	85.95
	15x15	40.01	52.73	68.19	68.79	57.47
	6x6	231.53	227.87	211.53	167.35	209.57
White	9x9	179.28	198.16	176.96	193.96	187.21
Pine	12x12	169.62	126.87	151.14	119.38	141.47
	15x15	127.37	119.38	132.91	125.90	126.02

TABLE A10. Total Standing Volume (Cubic Feet per Acre) by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	5076.32	6491.77	6124.93	8889.16	6647.81
	9x9	4829.54	4700.35	5351.24	3768.92	4669.50
	12x12	4302.21	3741.59	4821.89	4030.45	4224.06
	15x15	3319.33	2339.74	4080.98	2141.05	2913.92
Shortleaf Pine	6x6	4091.54	3506.86	5748.19	4254.76	4401.72
	9x9	2031.22	3612.38	4111.67	3176.21	3235.09
	12x12	296.07	2056.55	1759.60	3352.97	1863.05
	15x15	253.23	553.24	2266.57	2186.65	1335.62
Virginia Pine	6x6	4832.09	2220.11	6047.77	4068.45	4563.04
	9x9	2683.60	3209.79	4120.51	3594.28	3397.86
	12x12	2373.41	2404.97	2533.19	2593.91	2478.48
	15x15	1097.34	1433.83	1954.12	2028.23	1632.11
White Pine	6x6	6359.46	6915.94	6170.41	5017.43	6115.86
	9x9	5168.33	6046.53	5408.87	6116.27	5688.59
	12x12	4849.13	3837.56	4480.22	3888.18	4255.34
	15x15	3931.85	3754.89	4109.59	3988.69	3934.64

TABLE A11. Average Total Value ($) of Sawtimber and Pulpwood per Acre by Species, Spacing and Block at Age Twenty-Two.

Species	Spacing	Block				Total
		1	2	3	4	
	6x6	3479.88	5244.00	4602.82	6241.50	4894.40
Loblolly	9x9	4738.92	3825.88	4580.60	3367.88	4134.99
Pine	12x12	4639.50	3823.05	5301.69	3915.45	4421.34
	15x15	3873.24	2761.92	4662.40	2199.34	3311.28
	6x6	2726.96	2880.40	3936.80	2743.80	3072.30
Shortleaf	9x9	1403.52	2620.70	2830.30	2174.60	2258.88
Pine	12x12	202.37	1975.18	1344.80	2827.58	1585.50
	15x15	204.05	481.00	1938.07	1793.54	1120.08
	6x6	3257.52	1511.97	4042.74	2651.76	3053.26
Virginia	9x9	1852.60	2297.60	2837.16	2527.35	2373.84
Pine	12x12	2180.00	1958.00	2342.40	2041.08	2131.50
	15x15	983.70	1407.94	1750.54	1745.24	1472.50
	6x6	6208.64	7840.56	4548.48	3784.80	5595.93
White	9x9	6579.87	8168.70	5796.59	7775.94	7081.80
Pine	12x12	7318.44	5784.75	6295.86	5073.75	6109.76
	15x15	6143.94	5882.85	6354.30	6079.56	6097.52

TABLE A12. Number of Stems per Acre by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block 1	Block 2	Block 3	Block 4	Total
Loblolly Pine	6x6	427	498	451	712	522
	9x9	258	381	359	224	305
	12x12	218	218	236	212	221
	15x15	129	108	159	109	124
Shortleaf Pine	6x6	688	261	712	498	540
	9x9	246	336	370	258	303
	12x12	54	109	139	259	140
	15x15	31	59	159	142	99
Virginia Pine	6x6	214	320	308	672	341
	9x9	224	311	381	325	310
	12x12	182	169	198	206	188
	15x15	86	86	128	154	115
White Pine	6x6	569	475	546	356	486
	9x9	314	392	336	314	339
	12x12	260	182	242	218	225
	15x15	159	142	162	162	151

TABLE A13. Percent Survival by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	35.3	41.2	37.3	58.8	43.1
	9x9	47.9	70.8	66.7	41.7	56.8
	12x12	72.0	72.0	78.0	70.0	73.0
	15x15	66.7	55.6	78.6	56.3	63.5
Shortleaf Pine	6x6	56.9	21.6	58.8	41.2	44.6
	9x9	45.8	62.5	68.8	47.9	56.3
	12x12	18.0	36.0	46.0	85.7	46.2
	15x15	16.1	30.4	82.1	73.4	51.3
Virginia Pine	6x6	17.6	26.5	25.5	55.6	28.2
	9x9	41.7	57.8	70.8	60.4	57.7
	12x12	60.0	56.0	65.3	68.0	62.3
	15x15	44.6	44.6	66.1	79.7	59.5
White Pine	6x6	47.1	39.2	45.1	29.4	40.2
	9x9	58.3	72.9	62.5	58.3	63.0
	12x12	86.0	60.0	80.0	72.0	74.5
	15x15	82.1	73.2	83.9	83.9	78.0
Total		49.8	51.8	63.4	62.1	56.7

TABLE A14. Mean Height (Feet) by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	71	77	69	74	73
	9x9	75	70	67	69	70
	12x12	71	69	67	73	70
	15x15	74	79	69	67	73
Shortleaf Pine	6x6	60	60	61	60	60
	9x9	59	64	63	60	61
	12x12	50	62	59	58	58
	15x15	53	54	60	57	57
Virginia Pine	6x6	57	64	64	61	62
	9x9	64	65	62	63	63
	12x12	59	63	58	57	59
	15x15	59	56	57	56	57
White Pine	6x6	76	80	79	78	78
	9x9	80	81	75	79	79
	12x12	77	78	79	76	77
	15x15	80	80	83	76	79

TABLE A15. Mean Diameter at Breast Height (Inches) by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	8.9	8.9	8.9	9.0	9.0
	9x9	11.5	9.4	10.2	10.0	10.1
	12x12	12.2	11.5	12.0	10.9	11.7
	15x15	14.8	14.4	13.4	11.4	13.5
Shortleaf Pine	6x6	7.0	9.5	7.4	6.9	7.5
	9x9	8.7	8.8	8.5	8.4	8.6
	12x12	7.6	11.1	9.2	9.4	9.5
	15x15	8.8	9.2	10.0	9.9	9.8
Virginia Pine	6x6	6.8	6.4	8.0	6.2	6.9
	9x9	8.7	8.6	8.9	8.0	8.6
	12x12	10.4	10.0	9.7	9.7	10.0
	15x15	10.9	11.1	10.5	10.0	10.6
White Pine	6x6	9.0	10.3	8.8	9.3	9.3
	9x9	11.4	10.4	10.5	11.9	11.0
	12x12	12.5	12.7	11.9	11.7	12.2
	15x15	14.1	14.2	13.8	13.6	13.9

TABLE A16. Mean Value ($) per Tree by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block 1	Block 2	Block 3	Block 4	Total
Loblolly Pine	6x6	16.47	17.20	14.17	14.92	16.13
	9x9	33.20	16.91	21.25	21.57	22.36
	12x12	35.11	29.54	31.95	27.41	31.05
	15x15	54.40	53.89	42.05	31.20	45.70
Shortleaf Pine	6x6	6.59	16.86	7.76	6.53	8.49
	9x9	12.63	13.07	12.07	11.86	12.33
	12x12	8.01	26.25	15.56	16.85	17.79
	15x15	10.66	13.90	19.56	18.32	17.96
Virginia Pine	6x6	5.21	6.35	8.41	4.57	6.45
	9x9	10.51	11.75	11.08	9.13	10.78
	12x12	19.61	17.54	16.12	15.45	17.20
	15x15	21.16	22.36	19.68	16.17	19.59
White Pine	6x6	22.62	32.55	15.83	22.32	22.90
	9x9	40.79	37.06	29.63	44.69	37.73
	12x12	51.86	56.29	47.44	44.48	49.86
	15x15	70.22	68.66	66.64	59.23	66.18

TABLE A17. Basal Area (Square Feet per Acre) by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block				Total
		1	2	3	4	
	6x6	192.87	225.42	202.84	320.86	241.96
Loblolly	9x9	194.16	187.94	210.47	126.58	178.82
Pine	12x12	182.07	162.70	190.20	142.56	169.25
	15x15	157.81	124.16	159.81	81.18	128.69
	6x6	192.80	134.68	220.58	136.39	175.09
Shortleaf	9x9	105.96	145.82	149.11	103.39	125.30
Pine	12x12	18.65	74.66	66.40	130.84	72.56
	15x15	13.60	28.08	89.55	78.10	53.53
	6x6	55.80	77.20	109.93	144.61	93.78
Virginia	9x9	93.85	130.12	167.96	117.83	128.12
Pine	12x12	111.70	95.32	105.94	108.23	105.60
	15x15	57.04	60.03	78.28	87.00	72.08
	6x6	274.89	298.66	239.30	174.02	246.85
White	9x9	231.20	257.34	214.76	251.75	238.44
Pine	12x12	237.55	174.90	205.95	200.15	204.94
	15x15	185.76	165.40	178.81	173.15	169.87

TABLE A18. Total Standing Volume (Cubic Feet per Acre) by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block 1	Block 2	Block 3	Block 4	Total
Loblolly Pine	6x6	7083.57	8823.27	7172.34	11935.70	8970.76
	9x9	7452.98	6767.46	7238.37	4459.98	6450.18
	12x12	6562.41	5734.99	6491.29	5245.51	6008.73
	15x15	5825.78	4832.35	5621.17	2990.84	4782.04
Shortleaf Pine	6x6	6682.61	4577.31	7596.36	4734.24	6033.77
	9x9	3556.60	5205.97	5240.72	3545.83	4356.91
	12x12	549.04	2544.10	2220.22	4357.86	2427.69
	15x15	415.73	859.65	2996.16	2519.49	1743.94
Virginia Pine	6x6	1656.63	2567.86	3484.43	4624.35	2988.43
	9x9	2979.44	4246.13	5195.21	3721.76	4064.27
	12x12	3349.22	2967.63	3139.20	3151.91	3165.36
	15x15	1678.81	1738.19	2281.82	2492.79	2100.89
White Pine	6x6	9857.43	10863.03	8556.16	6419.19	8858.31
	9x9	8305.82	9728.01	7225.85	8879.20	8508.69
	12x12	8356.96	6299.01	7417.58	6153.46	7066.17
	15x15	6784.73	5915.72	6658.56	5877.83	6100.42

TABLE A19. Average Total Value ($) of Sawtimber and Pulpwood per Acre by Species, Spacing and Block at Age Thirty.

Species	Spacing	Block				Total
		1	2	3	4	
Loblolly Pine	6x6	7035.10	8568.54	6386.37	10621.27	8152.78
	9x9	8555.31	6440.63	7620.23	4833.30	6862.30
	12x12	7646.53	6433.69	7539.09	5804.25	6856.05
	15x15	7021.82	5796.17	6687.49	3397.78	5694.54
Shortleaf Pine	6x6	4536.08	4400.60	5521.91	3251.37	4427.51
	9x9	3112.59	4391.73	4462.97	3057.44	3756.18
	12x12	435.96	2858.93	2165.23	4370.17	2448.96
	15x15	331.67	817.08	3110.42	2604.07	1746.36
Virginia Pine	6x6	1112.73	2032.77	2593.42	3072.94	2092.62
	9x9	2354.86	3651.80	4222.16	2966.43	3293.22
	12x12	3559.09	2970.91	3183.70	3178.67	3223.25
	15x15	1828.69	1932.54	2516.75	2494.86	2203.62
White Pine	6x6	12879.11	15447.20	8640.17	7941.46	11231.54
	9x9	12795.82	14531.22	9959.61	14018.24	12826.23
	12x12	13490.89	10215.79	11481.27	9687.44	11218.72
	15x15	11167.54	9731.97	10827.95	9623.97	9981.18

VITA

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